appear that a relationship between certain spectral characteristics and the distances of stars could hardly be credible, since it would appear like a correlation between two utterly unrelated subjects except in so far as the scattering of light in space might connect them. In fact, of course, it is not the distances but the absolute magnitudes of stars which have an influence on the character of the spectrum lines and such an effect, far from being improbable, is rather to be expected than not. The derivation of the distances is merely a by-product resulting from the combination of real, or absolute, with apparent magnitudes.

An important gain in the value of this method of determining stellar magnitudes and distances should result from an increase in the number of measured parallaxes of bright stars of small proper motion. Such stars will on the average prove to be very luminous, and, as already stated, the portion of the curves connecting line intensity with absolute magnitude is subject to much more uncertainty in the case of the high luminosity stars than in any of the others. It is probable that after such a revision has been made the method will find its most important application as a means of distinguishing these giant stars in the stellar system.

INVESTIGATIONS IN STELLAR SPECTROSCOPY. IV. SPECTROSCOPIC EVIDENCE FOR THE EXISTENCE OF TWO CLASSES OF M TYPE STARS

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The principal distinguishing feature of the M type of stellar spectrum on the Harvard system of classification is the presence of absorption bands due to titanium oxide. These bands increase in intensity for the successive subdivisions Ma, Mb, and Mc. The star α Orionis, in which they are present in moderate intensity, is selected as a typical Ma star by the Harvard observers. Since these bands may be seen faintly in stars of the K5 type of spectrum it is necessarily largely a matter of judgment whether in any given spectrum they are sufficiently strong to warrant classifying the star as Ma, or whether it should still be retained within the K type.

For types of spectra previous to M the principal basis of classification is the intensity of the hydrogen lines. These reach a maximum in the A type, and grow fainter in the successive types F, G, and K. Of the hydrogen lines in α Orionis, however, Miss Cannon, in the course of

her classification of the Harvard spectra, makes the statement that they are of about the same intensity as in α Tauri, a typical K5 star.[1]

The classification of the Mount Wilson stellar spectra in accordance with the Harvard system, a description of which is given in a previous communication,[2] is based upon a comparison of the intensities of the hydrogen lines with those of neighboring iron lines which are subject to relatively slight variation with type. A series of curves have been constructed giving the relationship between the relative intensities of these pairs of lines and the spectral type; and the determination of type is thus reduced to an estimation of the intensities of these lines. The stars used in the derivation of these curves are almost wholly stars of large proper motion, and in many cases have measured parallaxes of considerable size. They are, accordingly, stars of relatively low intrinsic brightness in general. This is true especially of the K5–K9 and Ma stars, nearly all of which, like 61 Cygni and Groom. 34, are of very low absolute luminosity. The curves derived in this way show a regular decrease in the intensity of the hydrogen lines throughout the range of spectrum employed, the lines in K5 stars being fainter than in K0, and in the Ma stars fainter than in K5. In fact the hydrogen lines are barely visible in most of the M stars used in the construction of the curves.

When these results are applied to the M stars of high luminosity a very anomalous condition is found. The presence of the bands places these stars definitely in the M type, but the hydrogen lines are of quite abnormal intensity. Thus α Orionis, with bands of type Ma, if classified on the basis of its hydrogen lines would become G2. This is the most remarkable case found as yet, but all of the high luminosity M stars show a strong tendency in the same direction. The results of a classification of 48 stars of types Ma to Mc on the basis of the intensities of their hydrogen lines may be summarized as follows:

TABLE I

TYPE	NO. OF STARS	TYPE	NO. OF STARS	TYPE	NO. OF STARS
G2	1	G7	9	Ma	20
G3	1	G8	10	Mb	18
G4	3	G9	4	Mc	10
G5	3	K0	4		
G6	11	K1	2		

Accordingly, the most advanced type found for any of these stars from a determination of the intensities of their hydrogen lines is K1, and the average type is G7. This is as against an average type of Mb given by

the intensities of the bands. Two conclusions may be drawn at once from these results: First, that the Harvard system of classification, in which the M type stars are all included in one group on the basis of the presence of the bands, fails entirely to discriminate between the spectral peculiarities of the high and the low luminosity M stars; and second, that the intensity of the hydrogen lines in the M stars probably varies with the absolute magnitude, the brighter stars having the stronger hydrogen lines.

A method of determining the absolute magnitudes of stars from the characteristics of certain of their spectral lines has been described in a previous communication.[3] The essential feature of this method is the use of the two lines λ 4216 of strontium and λ 4455 of calcium, the intensities of which appear to be connected directly with the intrinsic brightness of the stars in whose spectra they occur. The intensities of these lines relative to other lines in the spectrum are estimated, and a numerical relationship is established between these intensity ratios and absolute magnitude by means of a selection of stars of known parallax. In this way the following formulae applicable to stars of types G8–K4 have been derived. M is the absolute magnitude, and Δ the intensity ratio for each pair of lines.

$\frac{4216}{4250}$	$\frac{4455}{4462}$	$\frac{4455}{4494}$
$M = -1.6\Delta + 4.7$	$M = +1.6\Delta + 5.1$	$M = +2.3\Delta - 0.3$

It is this set of formulae which has been used in the case of the M stars of high luminosity. The average type of these stars was found to be G7, which is sufficiently near the limits of the group to admit of the application of the corresponding equations. Summarized briefly the results for the high and the low luminosity stars are as follows:

	Average Spectrum	*No. of Stars*	*Average M*	*Range of M*
High luminosity	G7	48	+1.4	−1.0 to + 3.4
Low luminosity	Ma	10	+10.3	+9.8 to +10.7

Of the high luminosity stars only two, α Orionis and Boss 660, have negative values of the absolute magnitude, and only five stars have values exceeding 2.0. The remaining 41 stars have magnitudes ranging between 0.0 and 2.0. It is clear, accordingly, that on the basis of absolute magnitude determinations the M stars fall into two clearly defined groups, separated by an interval of about 7 magnitudes within which no intermediate values have been found.

The spectroscopic evidence, therefore, confirms the hypothesis of Hertzsprung and Russell that the M type stars are divided into two

groups of 'giant' and 'dwarf' stars.[4] This hypothesis was based primarily on parallax observations. The absolute magnitudes calculated from these parallaxes showed almost a complete absence of stars of brightness intermediate between exceedingly luminous stars like α Orionis, and extremely faint stars such as Groom. 34. It has been thought probable by some astronomers that this apparent gap is due to the fact that parallax determinations have hitherto been restricted almost entirely to a few stars of great apparent brightness, and to stars of very large proper motion, while the connecting links would probably be found among stars of moderate apparent brightness and moderate proper motion. The spectroscopic evidence, however, is based upon numerous stars of just this character, and the gap still appears to persist.

These results may be summarized briefly as follows. Two groups of M stars are indicated clearly by an examination of the intensities of the hydrogen lines: in the first the hydrogen lines are very strong; in the second they are very faint. A computation of the absolute magnitudes of these stars on the basis of certain peculiarities in their spectra shows the existence of these groups distinctly. Connecting links over a range of 7 magnitudes are entirely lacking, and the conclusion seems to be unavoidable that among these stars the intensity of the hydrogen lines varies with the absolute magnitude.

The results given for the high and the low luminosity stars may be used to furnish an approximate relationship between the intensities of the hydrogen lines and absolute magnitude. Thus we have for $H\beta$:

	Average M	*Intensity of Hβ*
High luminosity stars..............................	+ 1.4	+1.9
Low luminosity stars..............................	+10.3	−3.0

Assuming a linear relationship between intensity and absolute magnitude we obtain the equation

$$M = -1.8 \, \Delta + 4.8$$

This is remarkably similar to the corresponding equation found for the line λ 4216 and given on a preceding page. It seems probable, therefore, that in the case of the M stars, at least, the hydrogen lines may be used for absolute magnitude determinations in the same way as λ 4216.

There is, however, one characteristic of the spectra of these high luminosity stars which must be taken into consideration when use is made of the relative intensities of the hydrogen lines. This is a relationship which appears to exist between the intensities of the hydrogen lines and the intensities of the bands, the hydrogen lines being stronger when the

bands are stronger. There are occasional exceptions to this rule, as in the case of α Orionis, but in general the effect is well marked. Thus if we compare the intensity of the hydrogen line $H\beta$ in the stars having bands of moderate intensity with that in stars in which the bands are very strong we find the following result:

No. of Stars	*Intensity of Bands*	*Intensity of* $H\beta$
13	Moderate	+1.2
20	Strong	+1.7

It is of interest to note in this connection that the computation of the absolute magnitude shows that the Mc stars, in which the bands are exceedingly strong, are brighter on the average than those in which the bands are less intense.

Among the high luminosity stars are some with proper motions of moderate size. The absolute magnitudes of these stars should average somewhat less than those of the very small proper motion stars which constitute the remainder of the list. An analysis of the results for the 48 stars gives the following comparison. M is the absolute magnitude and m the apparent magnitude.

No. of Stars	*Average P.M.*	*Average m*	*Average M*
15	0.″155	5.06	1.54
33	0.017	5.49	1.29

After making the necessary correction for the difference in the values of the average apparent magnitude we find the large proper motion stars to be about 0.7 magnitude fainter than those of small proper motion. This furnishes a check on the accuracy of the absolute magnitude determinations.

The variations in the intensities of the hydrogen lines and of the two lines used in the computation of absolute magnitude form only a part of a more general difference in the spectral characteristics of the high and the low luminosity M stars. The results of a detailed comparison of the spectrum of α Orionis (M = -1.0) with that of Lal. 21185 (M = $+$ 10.6) and of other intrinsically faint stars may be summarized as follows:

	α Orionis	*Lal. 21185*
Enhanced lines, especially those due to *Fe, Ti, Sr*, and *Y*....	Strong	Weak
Hydrogen lines..	Strong	Weak
Low temperature lines of *Ca, Ti, Cr*, and *Sr*................	Weak	Strong
λ 4227 of calcium..	Weak	Very strong

Results of a character very similar to these were found in a comparison of the spectra of α Tauri (K5) and 61^1 Cygni (K8) two stars differing

in brightness by nearly 8 magnitudes, and also in the case of the N and the R type stars of the Harvard classification. The differences, accordingly, appear to be fundamental in nature, and associated with the intrinsic brightness of the stars of the several types. They indicate a lower temperature in the absorbing gases constituting the atmospheres of the fainter stars, and are analogous in many respects to those observed in the spectrum of sun-spots.

The division of the M type stars into two well-defined classes of high and low luminosity stars raises the question at once whether a corresponding separation may be found among other types of spectra. From his discussion of parallax observations Russell concludes that such a

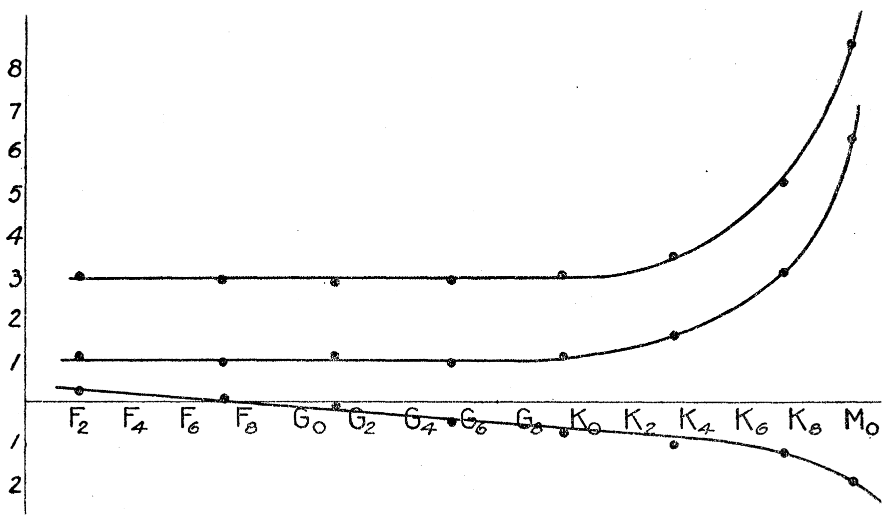

FIG. 1. CURVES SHOWING VARIATION WITH SPECTRAL TYPE OF THE RELATIVE INTENSITIES OF PAIRS OF LINES USED IN ABSOLUTE MAGNITUDE DETERMINATIONS.

Top curve, $\frac{4455}{4494}$; Middle curve, $\frac{4455}{4462}$; Bottom curve, $\frac{4216}{4250}$.

separation does exist among the K stars. The spectroscopic evidence tends to support the existence of such a division at least for the K5–K9 stars. This evidence is of just the same character as that in the case of the M type stars, and is of two kinds. First, the hydrogen lines have an abnormally high intensity in the very luminous stars, and there is an absence of intermediate values of the intensity between these and the low values characteristic of the fainter K5–K9 stars. Second, computations of absolute magnitude indicate the existence of two mean magnitudes, one high and the other low, about which the values for the individual stars showed a marked tendency to gather. This effect is not so well defined as for the M stars, but still very clear. It may perhaps

be shown to the best advantage by a reproduction of the curves representing the estimated intensity differences for the pairs of lines used in the determinations of absolute magnitude. These are given in figure 1. The curves are based upon essentially all of the stars with observed parallaxes for which we have spectral observations. Each point on the curves represents the mean for a considerable number of stars; and, as these stars differ in absolute magnitude, the corresponding intensity differences for the pairs of lines will differ. In types F and G the higher and lower luminosity values and the line differences balance one another so nearly that the successive values show but a gradual change, and the curves make but a slight angle with the horizontal axis. At about K3, however, the curves begin to bend abruptly, and the remaining types depart from the axis very rapidly. This is due to the absence of stars of even moderately high luminosity among those upon which the curves are based.

The corresponding curves for the high luminosity stars of these types run nearly parallel to the horizontal axis. We find, accordingly, both for types K5–K9 and M, a branching of the curves which points directly toward the existence of a division into two distinct groups. This evidence is based upon all of the spectroscopic material available.

In conclusion reference should be made to the necessity of adding to the symbols used in the Harvard system of classification for the M stars some character or figure which shall serve to distinguish between the spectral characteristics of the high and the low luminosity stars. The most important of these is the difference in the intensity of the hydrogen lines. Accordingly, though somewhat cumbersome in practice, I can think at present of no method which would convey the necessary information in any better way than by adding to the classification based on band intensity the corresponding classification based on hydrogen line intensity. Thus Mb (G6) would indicate a spectrum in which the bands are strong but the hydrogen lines give a type of G6. On this basis the low luminosity M stars would be of normal type and would require no suffix.

[1] *Ann. Obs., Harv. Coll.*, 28, 160.
[2] These *Proceedings*, 1, 481 (1915).
[3] These *Proceedings*, 2, 143 (1916).
[4] Summarized by Eddington in *Stellar Movements and the Structure of the Universe*, pp. 170–177.